An ISO Survey of PAH Features in Ultraluminous Infrared Galaxies

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Abstract. We have obtained ISOPHOT-S low resolution mid-infrared spectra of a sample of 60 Ultraluminous Infrared Galaxies (ULIRGs). We use the strength of the 'PAH' mid-infrared features as a discriminator between starburst and AGN activity, and to probe for evolutionary effects. Observed ratios of PAH features in ULIRGs differ slightly from those in lower luminosity starbursts. We suggest that such PAH ratio changes relate to the conditions in the interstellar medium in these galaxies, and in particular to extinction.

1. Introduction

The nature of ultraluminous infrared galaxies has been the subject of lively debate since their discovery by IRAS more than a decade ago. Although evidence for both starburst and AGN activity in ULIRGs has accumulated during this period, the question as to which generally dominates the luminosity has remained largely unsolved, mainly due to observational difficulties associated with their large dust obscuration.

With the advent of ISO, sensitive mid-infrared spectroscopy became available as a new tool capable of penetrating the obscuring dust. Fine structure line and PAH feature observations with SWS and ISOPHOT-S of a sample of 15 bright ULIRGs suggest that most are starburst-powered (Genzel et al. 1998). However, this sample is too small to search for luminosity or evolutionary effects. Using only PHT-S it has subsequently proved possible to extend to fainter sources and increase to 60 the number of ULIRGs observed over the wavelength range containing the 6.2, 7.7, 8.6, and 11.3μm features commonly attributed to polycyclic aromatic hydrocarbons (PAH). ISO data confirm groundbased observations of these and a companion at 3.3μm which first demonstrated that these features are strong in starburst galaxies but weak or absent in classical AGNs. We have therefore used the line to continuum ratio of the most prominent, 7.7μm, feature as our primary discriminator between starburst and AGN activity.

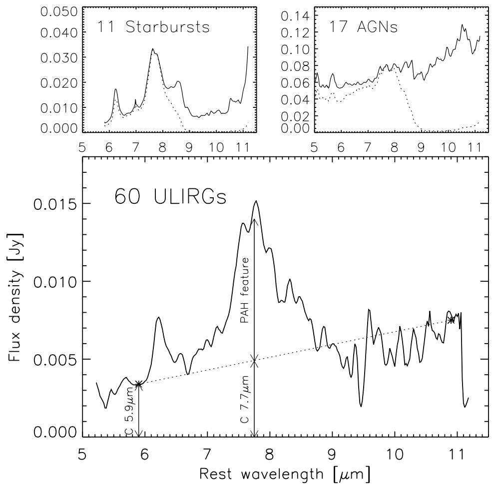

Figure 1. Average ISOPHOT-S spectrum of all ULIRGs observed, individually scaled to S_{60}=1Jy. Average spectra of starburst galaxies and AGNs are added for comparison. The dashed lines represent these spectra after applying an additional A_V=50 foreground extinction

2. A PAH Survey of ULIRGs

Our sample of 60 ULIRGs is drawn from the 1.2 Jy survey (Fisher et al. 1995). No infrared color criteria were applied to avoid biasing the sample in AGN content. The average of all 60 ULIRG spectra, individually scaled to S_{60}=1Jy to give all sources equal weight (Fig. 1), clearly shows the PAH features at 6.2, 7.7, and 8.6μm but relatively weak continuum. Comparison with the starburst and AGN templates provides a first and direct indication that ULIRGs are, on average, starburst-like. Fig. 1 also illustrates our method for extracting PAH and continuum data from the individual spectra. We find that

- About 80% of all the ULIRGs are found to be predominantly powered by star formation but the fraction of AGN powered objects increases with luminosity. Whereas only about 15% of ULIRGs at luminosities below $2 \times 10^{12} L_\odot$ are AGN powered this fraction reaches about half at higher luminosity.

- The PAH feature-to-continuum ratio is anticorrelated with the ratio of feature-free 5.9μm continuum to the IRAS 60μm continuum, confirming suggestions that strong mid-IR continuum is a prime AGN signature. The location of starburst-dominated ULIRGs in such a diagram is consistent with previous ISO-SWS spectroscopy which implies significant extinction even in the mid-infrared.

- We have searched for indications that ULIRGs which are advanced mergers might be more AGN-like, as postulated by the classical evolutionary

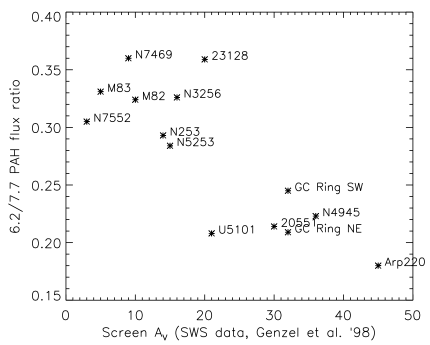

Figure 2. Anticorrelation between the ratio of the 6.2 and 7.7μm PAH features and extinction

scenario. No such trend has been found amongst those objects for which near infrared images are available to assess their likely merger status.

See Lutz et al. (1998) for a discussion of these results.

3. PAH ratios as indicators of extinction and ISM conditions

Observed ratios of the PAH features in ULIRGs differ slightly from those in lower luminosity starbursts which exhibit very homogeneous PAH properties (Fig. 1). The ratio of the 6.2/7.7μm features is lower and the 8.6μm feature is a shoulder to the 7.7μm one rather than a well-defined feature. This behaviour is more pronounced in some individual spectra, e.g. for Arp 220. One possibility is that the weakness of the 6.2μm feature reflects the unusual conditions of the ULIRG interstellar medium, as sometimes observed in galactic sources. For compact H II regions, Roelfsema et al. (1998) find 6.2/7.7 ratios which on average are lower than for 'typical' H II regions, and for some sources high 8.6/7.7 ratios which might be linked to an intense radiation field.

A second effect is the influence of strong extinction which is already suggested by the similarity of the average ULIRG spectrum and the obscured starburst spectrum of Figure 1. Extinction suppresses the 6.2, 8.6, and 11.3 features in comparison to the one at 7.7μm. Figure 2 demonstrates that this effect is indeeed at work: There is an anticorrelation between 6.2/7.7 ratio and extinction estimated from independent ISO-SWS spectroscopy (Genzel et al. 1998 values, converted to screen case). Of the starburst templates shown, extinction approaches ULIRG levels only for NGC 4945 and the molecular ring encircling the center of our Galaxy. Interestingly, these are the only spectra in that group which also show low 6.2/7.7μm flux ratios. Further, as in our average ULIRG spectrum, their 8.6μm features appear as a shoulder to the 7.7μm feature rather than as a separate feature, due to suppression in the wings of the silicate absorption feature.

While extinction appears to be the prime cause for unusual PAH ratios in the ULIRGs and source like NGC 4945, we suggest that both extinction

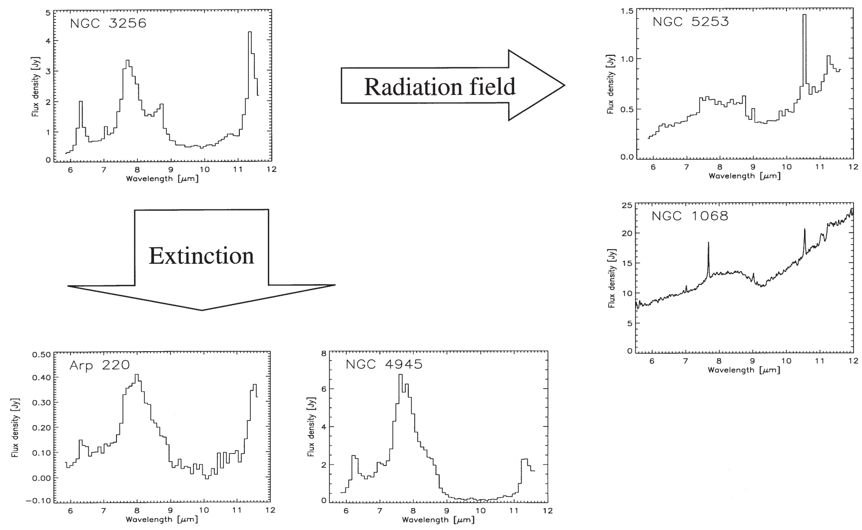

Figure 3. A scenario of how extinction and intense radiation fields may affect mid-IR PAH spectra of galaxies. NGC 3256 represents starbursts and normal galaxies.

and intense radiation fields govern the appearance of the mid-infrared PAH spectra of galaxies (Fig. 3). Galaxies like the starbursting dwarf NGC 5253 and the circumnuclear region of the Seyfert 2 NGC 1068 show a broadish 7.7-8.6 PAH complex with high 8.6/7.7 ratio, just like the inner parts of HII regions (Roelfsema et al. 1998, Verstraete et al. 1996).

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